CPC(HEP & NP), 2009, **33**(X): 1—4 Chinese Physics C Vol. 33, No. X, Xxx, 2009

Neutron Nuclear Data Evaluation of Actinoid Nuclei for CENDL-3.1

CHEN Guo-Chang[1;1)] CAO Wen-Tian[2] YU Bao-Sheng[1]
TANG Guo-You[2] SHI Zhao-Min[2] TAO Xi[1]

[1] Laboratory of Science and Technology on Nuclear Data, China Institute of Atomic Energy, Beijing 102413, China;
[2] School of Physics & State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China

Abstract New evaluations for several actinoids of the third version of China Evaluated Nuclear Data Library (CENDL-3.1) have been completed during the period between 2000 and 2005. The evaluations are for all neutron induced reactions with Uranium, Neptunium, Plutonium and Americium in the mass range A=232-241, 236-239, 236-246 and 240-244, respectively, and cover the incident neutron energy up to 20 MeV. In present evaluation, much more efforts were devoted to improve reliability of nuclide for available new measured data, especially scarce experimental data. A general description for the evaluation of several actinoids data were presented.

Key words Actinoid, Nuclear Data, Evaluation, ENDF

PACS 24.10.-i, 25.85.Ec, 29.87.+g

1 Introduction

The new generation evaluated nuclear data library, CENDL-3.1, has recently been released by China Nuclear Data Center[1]. The evaluation CENDL-3.1 is needed for design of fission and fusion reactors and for shielding calculations. The actinoid nuclear data in CENDL-2.1[2] were re-evaluated taking account of new experimental data, new standard cross sections from ENDF/B-VI and using a new theoretical model calculation code. In addition to those nuclides, new 25 nuclides have been evaluated also during the period between 2000 and 2005. The evaluations are for all neutron induced reactions with Uranium, Neptunium, Plutonium and Americium in the mass range A=232-241, 236-239, 236-246 and 240-244, respectively, and cover the incident neutron energy up to 20 MeV. More detailed actinoid nuclides in CENDL-3.1 are listed in Table 1. Comparing with CENDL-2.1, the newly evaluations were ranked at "New".

In the CENDL-3.1 evaluation, much more efforts were devoted to improve reliability of nuclide for available new measured data, especially scarce experimental data. Major aspects of present evaluations are: systematic accumulation, correction and evaluation of all relevant experimental data; renormalization of the neutron data to ENDF/B-VI standard reaction cross sections; assessment of the applicability of several optical model potentials which obtained before 2000 year for actinoid calculations; interpretation of the experimental results in terms of nuclear theory to allow interpolation and extrapolation of the data into unmeasured energy regions; and finally, assembly of the experimental and theoretical results into formal evaluated nuclear data files that can be processed for use in applied nuclear programs. The report presents a general description for the evaluation of several actinoids data.

In the following sections, an overview of actinoid nuclear data of CENDL-3.1 in comparison with measurements and other database is presented.

Table 1. Actinoid nuclides in CENDL-3.1 database.

	CENDL-2.1	CENDL-3.1	New
U	235,238	232-241(10)	232-234,236,237,239-241
Np	237	236-239(4)	236,238,239
Pu	239,240	236-246(11)	236-238,241-246
Am	241	240-244(6)	240,242,242m,243,244

Received

1) E-mail: cgc@ciae.ac.cn

2 Resonance Parameters

Thermal fission and capture cross sections for actinoid nuclides were corrected and estimated averaging measurements with suitable weights according to method, neutron source, sample purity and so on. The negative and low-lying resonance parameters were modified to reproduce the thermal cross sections. The results of thermal fission and capture cross sections for some important actinoid nuclides are shown in Table 2. The resonance parameters were adopted from other databases. According to experimental data and benchmark results, modify some resolved resonance parameters. On the other hand, the resolved resonance parameters (RRP) of ^{236}Np and ^{238}Np, which were taken from G.B.Morogovskij[3] evaluation results, and the unresolved resonance parameters (URP) were obtained for ^{238}Np according to the resolved resonance parameters. The unresolved resonance parameters were determined so as to smoothly connect with the evaluated cross sections.

Table 2. Fission and capture thermal cross sections(b).

Nuclide	Fission	Capture
^{233}U	7.67654E+01	7.52080E+01
^{234}U	2.98537E-01	9.97503E+01
^{237}Np	2.02034E-02	1.60369E+02
^{238}Pu	1.70116E+01	5.61082E+02
^{240}Pu	6.40123E-02	2.87387E+02
^{241}Pu	1.01199E+03	3.61525E+02
^{242}Pu	1.04233E-03	1.91577E+01
^{241}Am	3.14232E+00	6.39448E+02
^{242}Am	2.09322E+03	2.18831E+02
^{242m}Am	6.39017E+03	1.22922E+03
^{243}Am	6.43805E-02	7.67044E+01

3 Evaluation Procedure

There is a significant amount of measurements with different method, facility and neutron source available for neutron reactions on several of the actinoids in present study. We obtained almost experimental data from the EXFOR/CINDA database at the Nuclear Data Section of IAEA, the Data Bank of the Nuclear Energy Agency in Paris, INIS database and relevant periodical literatures. Much of those experimental data more or less exit discrepancy each other for the same neutron reaction. For cross sections evaluation, mainly effort was concentrated on experimental data analysis and evaluation, which include systematic accumulation, correction and evaluation of all relevant experimental data, and renormalization of the neutron data to ENDF/B-VI standard reaction cross sections etc.

Much of the measurements for fission cross-section experimental data and prompt neutron multiplicities from fission reaction (nubar) are relevant to "standard" or other accurately measured reactions. The most of nubar measurements are relative to ^{252}Cf neutron multiplicities from spontaneous fission, which is very accurately known as 3.7692 ± 0.0047 [4, 5]. In the case of fission cross sections, the experimental data are frequently relative to the fission cross section of ^{235,238}U or ^{239}Pu. In present evaluations, all the measurements of fission cross sections ratios which were evaluated and corrected before convert them to absolute cross sections using the ENDF/B-VI standard cross section. And absolute fission cross section experimental data before ENDF/B-VI standard were normalized to ENDF/B-VI standard. For prompt nubar measurements were corrected to consist with IAEA recommendation[4, 5].

In general, the first step of the evaluation procedure is to accumulate, assess, normalize and correct the measurements for each isotope. According to fit the measurements for σ_{tot}, σ_{non} and elastic scattering angular distribution, the neutron optical model parameters (OMP) are obtained with the APMN code[6], which is a program for searching automatically an optimum set of neutron optical model parameters. The theoretical models which are adopted are mainly coupled-channel optical models (such as ECIS-95[7] code) and Hauser-Feshbach statistical plus pre-equilibrium theory (as FUNF[8] code). The sequence usually followed in the evaluations above resonance region is to optimize agreement of model calculation results to the evaluated experimental data including cross sections, differential cross sections and double differential cross section (DDX) by careful model parameter adjustment. After that assembly of the experimental and theoretical results into formal evaluated nuclear data files as ENDF format. The final step in the evaluations is to make fine modifications in prompt nubar and other data (generally within experimental uncertainties) to enhance agreement with simple fast critical benchmark measurements.

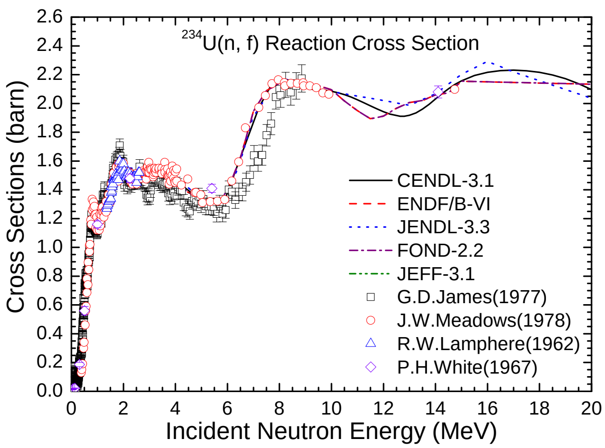

Fig. 1. Comparison of the evaluated data with the absolute measured data for ^{234}U(n, f) reaction.

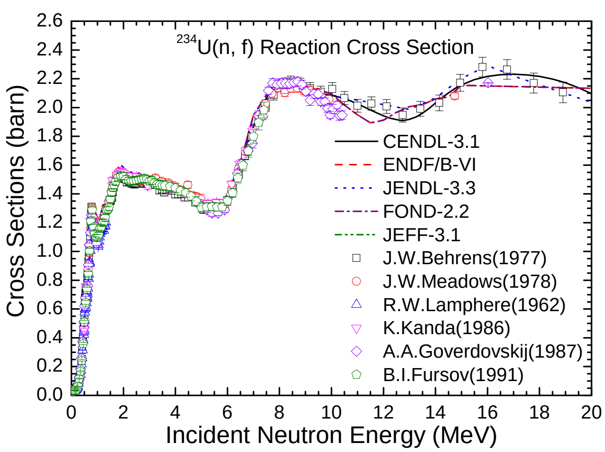

Fig. 2. Comparison of the evaluated data with the relative measured data for ^{234}U(n, f) reaction.

The comparison of the evaluated data with the absolute and the ratio experimental data is shown in Figs. 1 and 2. In Fig. 2, the ratio measurements were converted to the absolute one using ENDF/B-VI standard cross sections and compared with the evaluations. The discrepancy exists in each measurement as shown in Fig. 1. The ratio measurement is usually more reliable than the absolute as shown in Fig. 1. The original and correction measurements in comparison with each other are shown in Figs. 3 and 4. There exist discrepancy also for the relative ratio measurements as shown in Fig. 3. In consequence, analysis, modification, normalization and correction is necessary and clarify the discrepancies before using those experimental data in our evaluation. In Fig. 4 shows the correction relative ratio measurements in comparison with each other.

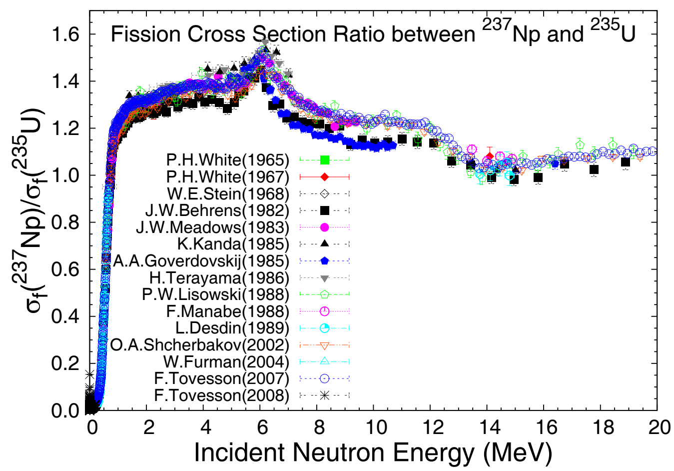

Fig. 3. Comparison of the original ratio measurements for ^{237}Np(n, f) reaction.

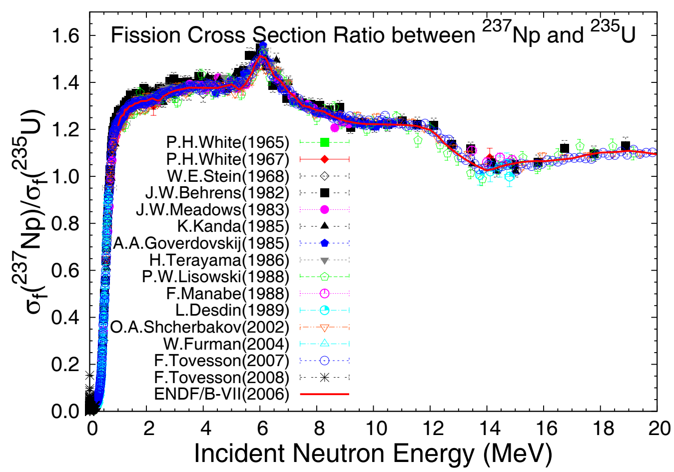

Fig. 4. Comparison of the corrected ratio measurements for ^{237}Np(n, f) reaction.

On the other hand, in order to obtain the reasonable recommended data of actinoid nuclides for scarce or no experimental data. Through evaluating available experimental data for Uranium, Neptunium, Plutonium and Americium isotopes, the change tend of some important reaction channel cross sections such as (n, f), (n, γ), (n, 2n), (n, 3n), etc. were researched. It was observed that the reaction channel data depend on the characteristic concerning even-odd (for the same Z), related fission barrier, level density, pair corrections etc. of actinoid nuclide. A systematic method to estimate the cross section for (n, f), (n, γ), (n, 2n), (n, 3n) etc. reactions were employed for interpolation and/or extrapolation suitable scarce data as shown in Fig. 5 for the comparison of (n, f) reaction cross sections between even mass of Uranium isotopes. For example, the systematic method was applied to obtain the scarce experimental data such as ^{246}Pu(n, f) reaction, which is only exist the experimental data at thermal energy. In order

to recommend the complete neutron data for ^{246}Pu, the theoretically calculation was employed based on the change tend to adjust the related fission barriers, level densities and pair corrections at saddle points for (n, f), (n, n′f) and (n, 2nf) phase of the even-even systematic of Plutonium. The (n, 2n), (n, 3n) etc. reaction cross sections and other qualities were calculated based on adjusted theoretical parameters in the same way as the even-even systematic of Plutonium. The systematic calculated fission cross section of ^{246}Pu is compared with JENDL-3.3, JEFF-3.1 and ENDF/B-VII, that the JEFF-3.1 and ENDF/B-VII were taken from JENDL-3.3 and the plot is shown in Fig. 6.

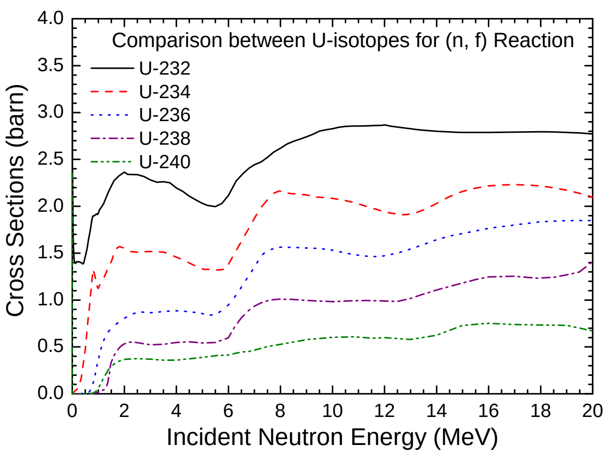

Fig. 5. Comparison of (n, f) reaction for even mass Uranium isotopes.

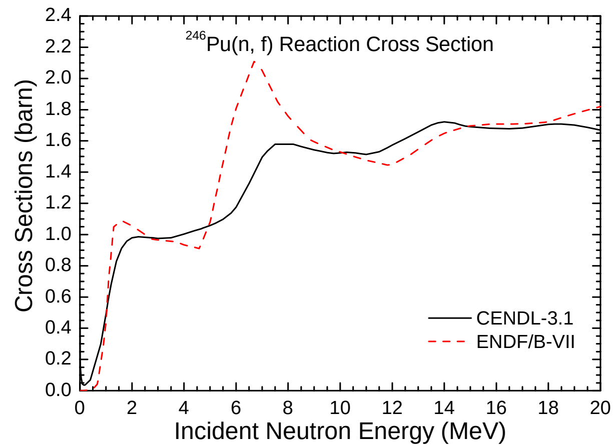

Fig. 6. Comparison of the evaluated data for ^{246}Pu(n, f) reaction.

4 Conclusion

Nuclear data of neutron induced reactions were evaluated for 31 actinoid nuclides from U to Am in the neutron energy range from 10^{-5} eV to 20 MeV during the period between 2000 and 2005. The evaluated results as a part of CENDL-3.1 were released in December 2009. Actinoid nuclear data in CENDL-3.1 were widely revised and improved, and 25 new actinoid nuclear data were added in comparison with CENDL-2.1.

References

1 The third version of China Evaluated Nuclear Data Library CENDL-3.1, (2009).
2 The second version of China Evaluated Nuclear Data Library CENDL-2.1, (1986).
3 G.B.Morogovskij and L.A. Bakhanovich, "Resolved Resonance Parameters for ^{236}Np," *INDC(CCP)-432*, p. 35, (2002).
4 A.L.Nichols, D.L.Aldama, M.Verpelli, "Handbook of Nuclear Data for Safeguards", *INDC(NDS)-0502*, (2007).
5 A.L.Nichols, D.L.Aldama, M.Verpelli, "Handbook of Nuclear Data for Safeguards: Database Extensions", *INDC(NDS)-0534*, (2008).
6 Shen Qingbiao, APOM94 code, Private Communication, (2003).
7 J. Raynal, "Notes on ECIS94", *Centre d'Etudes Nucleaires (Saclay), CEA-N-2772*, (1994).
8 ZHANG Jingshang, "User Manual of FUNF code for Fissile Material Data Calculation," CNIC-01782 (2005).